Renewable and Sustainable Energy Reviews 16 (2012) 4537–4542

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Will the aggregation approach affect energy efficiency performance assessment?

Hua Liao [a,b], Yi-Ming Wei [a,b,*]

[a] Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing 100081, China
[b] School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China

ARTICLE INFO

Article history:
Received 5 January 2012
Received in revised form
6 April 2012
Accepted 7 April 2012
Available online 26 June 2012

Keywords:
Energy aggregation
Energy efficiency
Elasticity of substitution

ABSTRACT

Aggregate energy is usually measured in the linear weighted summation of various energy types based on thermal dynamics laws. This measurement is scientific and acceptable in the physics or energy engineering world. However, it implicitly assumes that all energy types are perfectly substitutable and thus may result in distorted conclusions in energy-economy research. In economics world, production factors are usually non-linearly aggregated using Divisia approach, which is derived from microeconomic theory and considers the heterogeneity and imperfect substitutability among various energies. Using which "ruler" to measure the aggregate energy, the linear one or the others, will certainly affect the conclusions and energy saving incentives of the economic agents. Inequitable energy aggregations may bring out speculations or discouraged behaviors. According to China's current provincial energy efficiency performance assessment policy, the central government assigned the target of reducing the national aggregate energy intensity by 20% in 2006–2010 to provincial authorities in 2006. And in July 2011, the central government formally released the provincial assessment results based on conventional linear aggregation approach (coal equivalent). Our re-examination review this policy and show that the official results are quite different to that based on Divisia approach. From the perspective of economics, some local performances are overestimated and others are underestimated. To raise the equity and incentive compatibility of the assessment, we suggest the central take the imperfect substitutability or energy structure changes into consideration. We also discuss the difficulties and deficiencies when using Divisia aggregate approach.

Contents

1. Introduction

Turvey and Nobay [1] argued that *an economic phenomenon deserves an economic approach*. However, in energy-economy research or policy practice, this is not always the case. Many national or regional energy efficiency (or energy intensity) performance assessments are such cases. For example, IEA [2] reported the aggregate energy in terms of calorific or heating value, which is not economic approach but physical one. In this paper, we will review China's provincial energy intensity reduction assessment.

During the last two decades in the 20th century, China made great achievements on energy efficiency with 63% energy intensity reduction according to the official data [3]. However, contrary

* Corresponding author at: School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China. Tel./fax: +86 10 68911706.
E-mail addresses: ymwei@deas.harvard.edu, ymwei@263.net (Y.-M. Wei).

1364-0321/$ - see front matter © 2012 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.rser.2012.04.018

to most of the earlier predictions, and partly due to the rapid industrialization and energy intensive fixed asset investment, its energy consumption increased dramatically with a result of 2% intensity increasing in the first five years of this century[4]. In order to reverse the trend of intensity rising, China's central government set a challenging target of reducing its aggregate energy intensity by 20% in 2010 compared with that in 2005. And it assigned this target to local provincial authorities to reduce their provincial energy intensity by 12–22%. The quantitative assignments across provinces are different according to their local economic development levels and their informal negotiations with the central government (see Fig. 1(a)). For example, Beijing was required to reduce its energy intensity by 20%, and Hainan was allocated 12% reduction. According to the central authority's declaration, if a province failed to accomplish its assignment, its provincial governors' would probably be negatively affected on political promotion, and those with excellent performance will probably be promoted. And in June 2011, the central government officially released the provincial energy efficiency performance assessment communiqué: all the provinces successfully accomplished the assignment except for Xinjiang (this region was exempted because it encountered many other social difficulties), and among the 31 provinces, 18 of them over-fulfilled their assignments by 0–2%. Beijing performed the best with a 26% intensity reduction in 2006–2010 according to the communiqué. Many researchers and public media doubt the provincial raw data reliability. In this paper, we will not discuss the raw data quality. We only re-examine the aggregation of various energy types and compare the results based on different aggregation approaches.

In July 2011, China's central government assigned its new round of provincial energy conservation target for 2011–2015 (see Fig. 1(b)). So the measurement methods of aggregate energy intensity reduction are vital: appropriate measurement methods may incentive local authorities' energy efficiency behaviors. By contrast, inappropriate measurement methods may result in discouraged or speculative behaviors, which is inequitable and not helpful to reduce the whole country's energy intensity.

Though these administrative or incentive mechanisms on energy efficiency have some disadvantages, they come into some effects in the short run. Almost all the local governments have tried their best to achieve their aims. And in order to ensure the accuracy and reliability of the raw energy and GDP data, the central government has made great efforts to enhance the provincial data statistical regulatory. However, there are still some corners left that may have impacts on the equity of performance assessment. The energy aggregation approach is such one. According to China's current provincial statistical regulations, the linear weighted summation on various energy types is used for measuring aggregate energy, and this method is based on the first law of thermal dynamics and coal equivalent. In detail, coal, oil and gas are converted to standard thermal unit according to their heat content; hydro/nuclear/wind power, and net import/moving in power from other countries/provinces are converted to equivalent coal according to the average efficiency of thermal power generation (about 37%). We call it ***equivalent value approach***, which is one of the conventional linear aggregation approaches. However, different energy has different quality or work. Using exergy accounting, another linear aggregation approach, Chen and Chen [5,6] investigated China's energy consumption in detail based on the second law of thermodynamics. These two methods are scientific and acceptable in physics and energy engineering world. However, in economics world, linear aggregation methods implicitly assume that all the energy types are homogeneous, freely inter-convertible, and perfectly substitutable (i.e. the substitution elasticities among them are infinity). In fact, all energy types are heterogeneous and their substitution elasticities are finite. Their marginal products are unequal, which results in different market prices. The imperfect substitution elasticity assumption may result in partial or distorted conclusions in energy-economy research. The conventional linear aggregation approaches based on thermal dynamics are not good enough for energy-economic analysis. In microeconomics, aggregation theory and methodology are deeply studied and widely used in capital and labor accounting [7]. Derived from microeconomic theory, Divisia approach as well as Törnqvist or Sato-Vartia approach as its discrete types, are such super aggregations and widely used in composite price index [8] and composition analysis [9,10].

Using which "ruler" to measure the aggregate energy (the linear one, Divisia or others) will certainly affects the conclusions and energy saving incentives of the economic agents. Inequitable energy aggregations may bring out speculations or discouraged behaviors. In energy-economic empirical study, few literatures investigated the energy aggregation issue. Berndt [11] argued the advantages of Divisia. Cleveland et al. [12] illustrated three case-studies and showed that the conclusions were reversed by using the Divisia methods. And Stern [13] further investigated the energy quality issue from the perspective of economics. By investigating the aggregation approach, Liao and Wei [14] further explained China's energy intensity fluctuation in 1996–2005. In this paper, we re-examine the possible partial assessment on provincial energy efficiency performance, which have already been and will continue to be executed by China's central government.

2. Methodology and data sources

We will employ Divisia approach to account China's provincial aggregate energy intensity reduction during 2006–2010, and compare the results to that of the official "equivalent value method" (i.e. coal-equivalent method). Aggregate energy intensity is usually measured as aggregate energy consumption per unit of GDP. There are several methods to aggregate the various energy types. Divisia approach has many advantages over the conventional ones since it considers the imperfect substitutability among various energy types. Divisia approach can be described as the following:

$$d\ln E = \sum_{i=1}^{n} \frac{p_i e_i}{\sum_{i=j}^{n} p_i e_i} d\ln e_i = \sum_{i=1}^{n} s_i d\ln e_i \tag{1}$$

There are n energy types in the system. e_i represents the consumption of the ith energy type ($i=1,2,\ldots,n$), and E is the Divisia aggregate energy. p_i denotes the energy price of the ith energy type. And $s_i = p_i e_i / \sum_{i=1}^{n} p_i e_i$, represents the cost share. According to the above differential equation, the aggregate energy growth rate is equal to the weighted sum of the growth rates of various energy types, and the weights are their cost shares. If the growth rates of various energy types are equal to each other, the Divisia aggregate energy equals the linear aggregate. According to integral mean value theorem, we estimate the Divisia aggregate energy index by using the Sato-Vartia method. For more details about Divisia aggregation, please see Balk [8], Stern [13], Liao and Wei [14]. The elasticity of substitutions among energy types can also be derived based on Divisia approach.

We will re-examine China's provincial energy intensity reduction performance in 2006–2010 and compare it with the official assessment communiqué. There are 31 provincial authorities in mainland China. Unfortunately, till now only some provinces reported their energy balance in detail. Due to the data

unavailability, we can only investigate 13 provinces as illustrations. And we also examine the performance of the whole country. All physical energy data are sourced from provincial statistical yearbooks. The prices of coal, oil products and electricity refer to the ex-factory price (including value added tax) and are estimated based on China's Second National Economic Census. To a large extent, China's natural gas price is regulated by government, and it did not increase so much as the oil price in earlier 2008. Because energy prices (especially for coal) are quite different across provinces, we use the average price nationwide. We will further discuss the price issue at the end of this paper.

3. Results and discussion

3.1. Aggregate energy intensity based on different aggregations

Fig. 1 shows China and its 13 provincial aggregate energy intensity reduction measurement results in 2005–2006 (Year of 2005 index = 1). The bold curves represent the central government communiqué which is based on conventional equivalent value approach, and the thin ones refer to the results based on the Divisia method.

From the comparative static analysis perspective, the accumulative aggregate energy intensity reduction rate in seven provinces (Chongqing, Fujian, Guangxi, Hebei, Henan, Ningxia, Qinghai) during 2006–2010 are similar both measured in Divisia approach and in coal equivalent. This is due to little changes in energy cost structure in 2010 compared to that in 2005. For example, the cost share of coal, oil, natural gas and primary electricity (including net moved in from other provinces) are respectively 63.2%, 35.7%, 0.9%, 0.2% in 2005; and 65.2%, 32.3%, 1.9%, 0.6% in 2010.

While from the dynamic analysis perspective, the aggregate Divisia energy intensity reduction paths are quite different from the coal equivalent ones, i.e. the bold curves are not coincided with the thin ones. This is because the growth rates of various energy types are not the same with each other or the energy structure changes significantly. For example, coal consumption in Fujian decreased by 5.9% in 2010 compared with that in 2009, while the consumption oil, natural gas and primary electricity (including net moved in from other provinces) are dramatically rose by 41.9%, 238.5% and 25.5% respectively. That's the reason why the curve in Fujian went upward in 2010 instead.

3.2. Provincial energy efficiency performance re-examination

Difference between the bold and thin lines indicates that the "ruler" will certainly affects the energy efficiency performance assessment results. And different "ruler" will induce different energy saving incentives. Inequitable energy aggregations may bring out speculations or discouraged behaviors: when the aggregate energy is measured by coal equivalent, energy with high quality or high marginal products (such as oil and natural gas) will be used in priority, although it is not cost-effective since the oil and gas prices are higher than the coal price. More using of oil and gas and less using of coal is helpful to improve the "book value" when the central government assesses local energy efficiency performance. However, from the perspective of economics, this means distorted resource allocation and may cause inefficiency.

According to the official communiqué released in June 2011, Beijing's performance on energy efficiency ranked the best, with a 26.6% energy intensity reduction in 2006–2010. Definitely, Beijing has made great efforts to improve its energy efficiency and achieved great success. However, if we measure Beijing's aggregate energy by using Divisia aggregation approach, we will find that it reduced its energy intensity by 21.4% during this period, lower than the official report (still fulfilled the assignment). We can use the energy structure change as shown in Table 1 to further explain this phenomenon. Coal share impressively decreased from 43.3% in 2005 to 30.2% in 2010, and natural gas share increased near 7 percentages in the five years.

During 2006–2010, coal consumption in Beijing has an average reduction of 2.8% annually. While oil and natural gas consumption increased by 5.8% and 18.8% respectively as show in Table 2. The sum of the primary electricity consumption and the net moving

Table 1
Energy structure in Beijing (%).

Year	Coal	Oil	Natural gas	Primary electricity[a]
2005	43.3	28.3	7.6	20.8
2006	39.4	29.0	9.3	22.4
2007	36.2	30.6	10.0	23.2
2008	33.1	31.0	12.7	23.2
2009	30.8	30.7	13.7	24.7
2010	30.2	30.1	14.4	25.4

[a] Including the net moved electricity from other provinces.

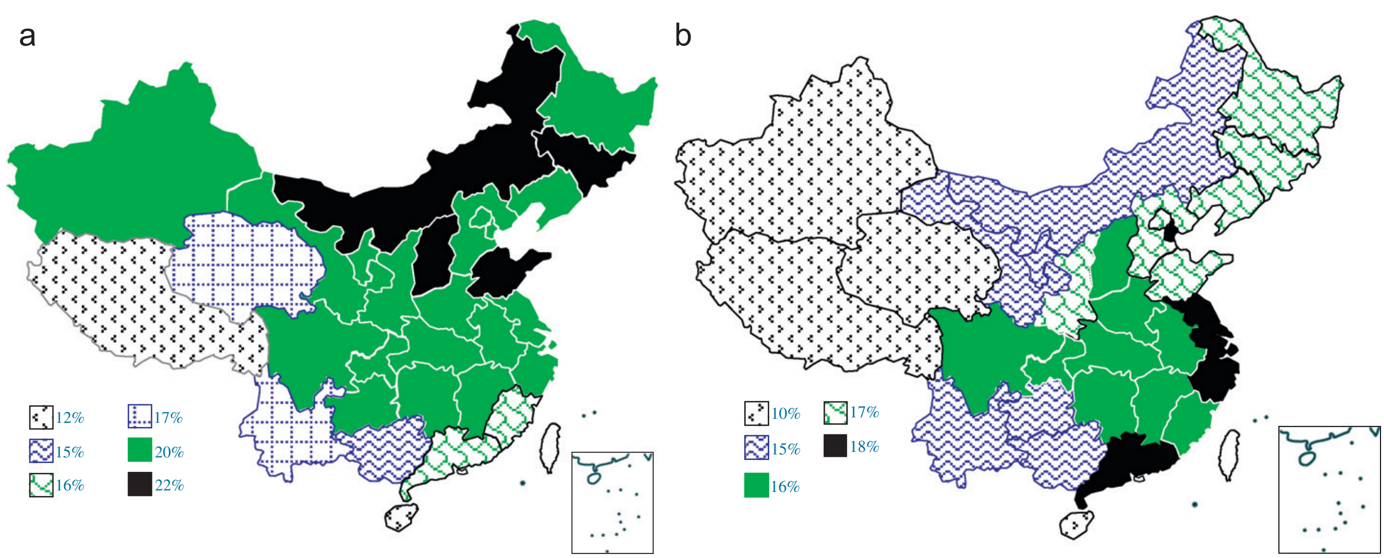

Fig. 1. China's provincial aggregate energy intensity reduction assignment. (*Note*: it is a schematic map and does NOT implicate the definite boundaries. The numbers refer to the assigned reduction rate).

Table 2
Energy indicators annual change rate (%).

Province	Aggregate energy consumption		Energy intensity		Energy consumption by type		
	Divisia	Coal equivalent	Divisia	Coal equivalent	Coal, primary electricity and net moved from other province	Oil	Natural gas
Beijing	6.2	4.7	−6.0	−4.7	1.5	5.8	18.8
Chongqing	10.2	9.7	−4.6	−4.2	9.4	9.7	12.5
Fujian	10.7	9.8	−3.5	−2.7	8.3	11.1	129.7
Gansu	5.5	6.3	−4.4	−5.1	6.6	4.1	8.2
Guangxi	9.9	10.2	−3.2	−3.5	10.5	8.9	6.0
Hebei	6.7	6.8	−4.4	−4.5	6.6	6.5	26.8
Henan	8.1	7.9	−4.4	−4.2	7.7	8.4	14.9
Jilin	7.5	9.3	−4.9	−6.5	9.9	5.3	23.5
Jiangxi	6.2	8.2	−4.4	−6.2	8.8	3.4	171.8
Ningxia	7.3	7.7	−4.4	−4.8	7.6	5.4	15.3
Qinghai	9.2	9.0	−3.7	−3.5	8.5	6.3	15.6
Shaanxi	10.4	9.8	−4.4	−3.8	8.4	10.1	27.4
Sichuan	10.2	8.7	−4.4	−3.1	9.4	9.7	12.5
Yunnan	10.3	7.6	−3.8	−1.3	6.8	14.3	−9.8
China	6.4	6.6	−4.1	−4.3	6.3	5.7	18.4

from other provinces has increased by 8.7% annually during 2006–2010 in Beijing. According to the conventional linear aggregation approach, electricity is measured by coal equivalent (average quantity of coal used for power generation). When considered this point, the aggregated coal and electricity consumption rose by 1.5% annually in average, which is also much lower than that of oil and natural gas. In general, oil and natural gas have much more marginal products than coal. One unit thermal heat increase in oil or natural can produce more GDP than that of one unit thermal heat increase in coal. This means that during 2006–2010, Beijing used less oil and natural gas to substitute more coal (in terms of heat content), which resulted in less energy consumption and more energy intensity reduction since they are measured in equivalent value. Therefore, equitably speaking, the central government communiqué overestimated Beijing energy efficiency performance to some extent. When taken the energy structure into accounts, Beijing may not rank the best across the provinces. (However, it should be remind that Beijing has already made great efforts on energy conservation and achieve great success.)

If we examine the aggregate energy intensity reduction in Gansu, Jilin and Jiangxi, the results are the inverse cases. According to the communiqué, their energy intensities decreased by 20.3%, 22.0% and 20.4% respectively during 2006–2010. However, if we measure their performance by using Divisia concept, they performed more excellent with their intensities reduction of 23.0%, 28.4%, 27.2%. That's because the growth rates of oil consumption were much lower than that of coal and electricity consumptions in these three provinces. Though natural gas consumption in Jiangxi increased dramatically, it can only substitute little coal due to its litter share (whether in terms of heat content or cost) in the aggregate energy consumption. Therefore, equitably speaking, the central government communiqué underestimated the energy efficiency performance of Gansu, Jilin and Jiangxi. If all the provincial energy efficiency performances were re-examined by using the Divisia method, the ranks may be quite distinct to the current one released by the central government. Some provinces tried to improve their "book performance" by keeping a relative higher growth rate of the oil and gas and lower growth rate of the coal. However, this trick is not suggested.

We also report the result for China in Fig. 2. During 2006–2010, China's aggregate energy intensity decreased by 19.8% when measured in Divisia approach, which is slightly faster than that in terms of coal-equivalent. That's because the cost share of natural gas rose faster than that of coal and primary electricity, i.e. the energy cost structure changed.

4. Policy implications and approach discussion

Capital and labor aggregation issues, as well as their impacts on economic growth accounting and economic policy research, were intensively studied in 1960s and 1970s. However, energy aggregation issues still did not get sufficient attention. When we measured the energy in Divisia concept in the aggregate economic-energy issues, some results may be distinct to that measured in conventional linear aggregate method, especially for regions with large energy structure changes,

What's more, different aggregate approaches may result in different incentive effects. In June 2011, China's central government released its local authorities' energy efficiency evaluation performance. From the perspective of economics, some provinces were underestimated, and some others overestimated. In July 2011, the central government assigned its new round of provincial energy conservation target for 2011–2015. Both the central authority and policy researchers highly emphasize the accuracy and reliability of the raw energy data when assessing the local performance. However, the linear aggregation method is taken for granted. We argue that the scientific and appropriate energy aggregation approach is also vital to assessment. The central government strictly calculates the aggregate energy using the coal-equivalent method and that is inequitable for those provinces with higher coal and electricity consumption growth rates such as Gansu, Jilin and Jiangxi. In the long run, it will improperly encourage speculations for local provinces to use more oil products/natural gas and less coal/hydropower, since the former two have more marginal products and can substitute more coal in terms of thermal. And the consequences may be the distorted market and economic growth, which is not good for China's development in the long run. It will also discourage local authorities to develop hydropower and wind power since they are measured according to thermal power generation efficiency. In this paper, we can only calculate 14 provinces' Divisia aggregate energy. If other provinces' data are available, the comparison may be more interesting.

Good energy efficiency policies should be those with incentive compatibility. When evaluating the local energy efficiency performance, if the central government taken the heterogeneity and imperfect substitutability among various energy types (i.e. energy structure changes) into consideration, the evaluation may be more equitable and some speculations may be reduced.

Though Divisia approach has many advantages over coal equivalent (or thermal equivalent) method in energy-economy

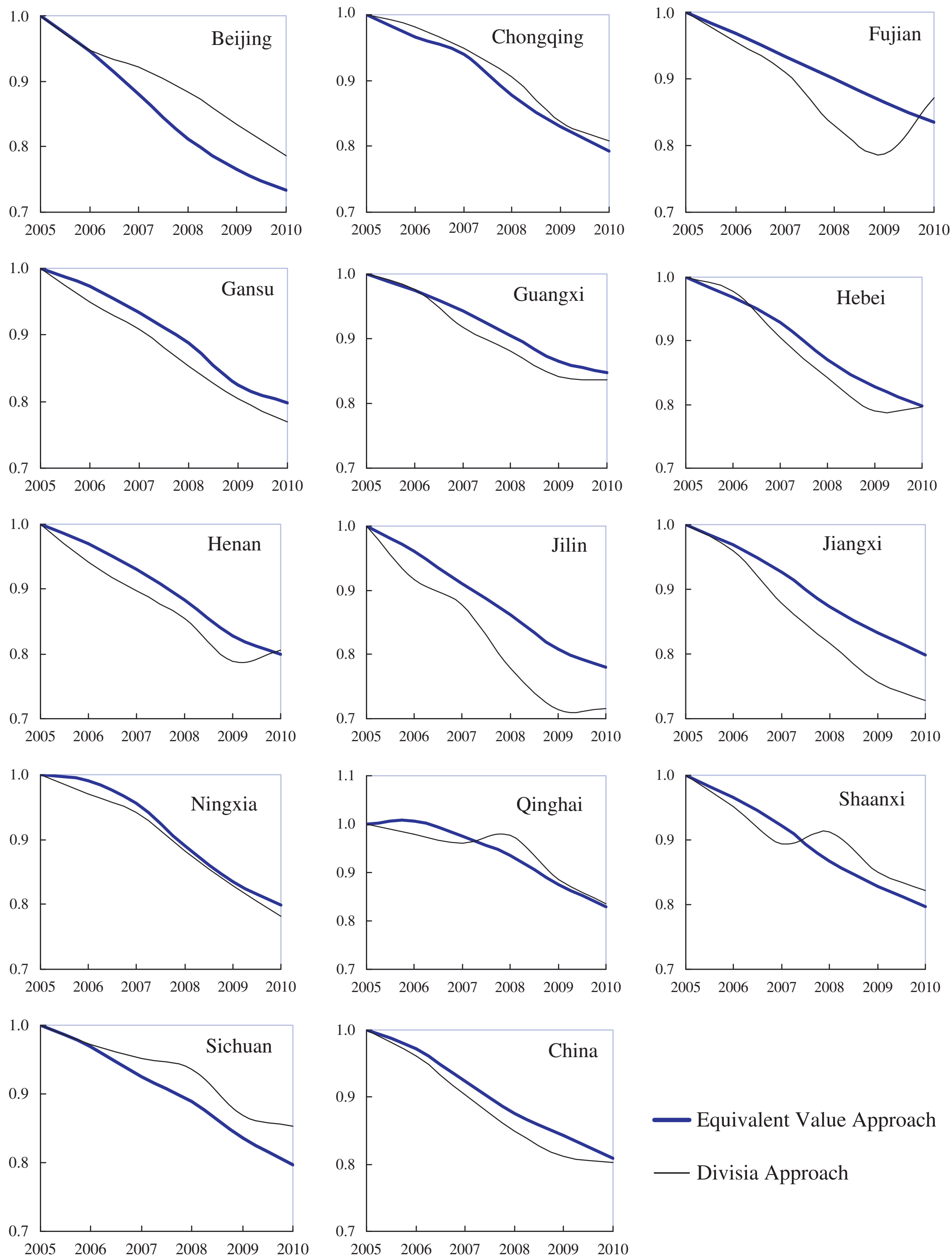

Fig. 2. China and its provincial energy intensity (2005 Indexed = 1.0).

analysis, it has some deficiencies too. Firstly, it reflects the demand-supply balance and implicitly assumes perfect market and the prices of various primary energy types were equal to their marginal products. But some energy prices are regulated inappropriately especially for the primary electricity and cannot reflect their environment externalities in many countries. Therefore, their practical trade prices are not always equal to their marginal products. To ensure the research accuracy, theoretically, the distorted trade prices can be replaced by the shadow prices which are difficult to calculate. Secondly, there are large price gaps across the provinces, especially for coal. If we use the same price for various regions, this may not reflect the fact. Though there is some difficulty to measure the price accurately, one thing is certain: oil and gas price are higher than coal price (in terms of thermal) in most regions. Sometimes we cannot measure the Divisia aggregate energy accurately, but we can qualitatively estimate the direction of partial effect of coal equivalent approach. For example, in this paper, we can judge whether the

provincial energy performance assessment is underestimated or overestimated. Therefore, we suggest the central taking the energy structure changes or Divisia concept into considerations when evaluating local authorities' performance by using coal equivalent approach. That will be helpful to improve the energy efficiency incentive compatibility.

Acknowledgments

The authors gratefully acknowledge the financial support from the "Strategic Priority Research Program" of the Chinese Academy of Sciences (XDA05150600), National Natural Science Foundation of China (71020107026, 70903066, 71041006), and Beijing Planning Office of Philosophy and Social Science (11JGC105), National Basic Research Program of China (2012CB955704). Hua Liao appreciates the good suggestions and comments from the seminar participants at US East-West Center. Hua Liao is also grateful to Mr. Xiaorong Liao for his hard and careful data collecting for this paper. We also would like to thank Professor L. Kazmerski, and the anonymous referees as well as the Journal Manager for their helpful suggestions and corrections on the earlier draft of our paper according to which we improved the content. The views expressed in this paper are solely authors' own and do not necessarily reflect the views of the supporting agencies.

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